

## UpTempO buoys for Understanding and Prediction

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### LONG-TERM GOALS

Our long-term goal is to better understand the evolution of heat content in the upper Arctic Ocean within the Seasonal Ice Zone (**SIZ**), both seasonally during summer warming and fall cooling, and interannually as sea ice retreats and the warming season lengthens. The effort is a contribution to the multi-investigator ONR-sponsored **SIZRS** project (SIZ Reconnaissance Surveys).

### OBJECTIVES

Our main objectives are to:

- (1) Develop the capability to observe upper ocean warming and cooling using air-deployed ocean drifting buoys.
- (2) Better understand the time and space scales of summer warming in the SIZ.
- (3) Investigate the relationships between sea ice retreat and upper ocean warming.

### APPROACH

SIZRS UpTempO buoy deployments: We are working with the Pacific Gyre (**PG**) buoy company (Oceanside, CA) to re-start an air-drop buoy capability that had grown dormant over the past several years. This program was initiated by Professor Peter Niiler at Scripps (UCSD) to drop 200 m long thermistor string buoys ahead of hurricanes in the Gulf of Mexico via Air Force C130 planes, the so-called “hurricane hunters.” In recent years, a surplus of buoys developed which coincided with a lack of technological updating. Thus our approach is to work with PG to develop a state-of-the-art air-drop buoy for polar applications. At the same time, we have been working with the US Coast Guard (**USCG**) to deploy these buoys from the Alaskan USCG C130 planes based out of Kodiak, Alaska as part of the SIZRS program.

Scientific analysis of multi-sensor ocean and ice observations: We are working with existing arctic buoy data as well as model output and satellite and in situ data on sea ice and upper ocean temperatures to better understand the time and space scales of upper ocean heating and cooling and

how these relate to sea ice retreat and advance. The idea here is to develop a measure of where and when we actually need to deploy buoys for climate applications, and how these needs might vary with ice conditions.

## WORK COMPLETED

### **I. Buoy deployments:**

All SIZRS air-deployed UpTempO buoys (**Figure 1**) have a surface hull with sensors for (i) surface air pressure, (ii) sea surface temperature, and (iii) submergence detection. The hull also contains alkaline batteries, Iridium and GPS antennae, and electronics. Below the hull hangs a 25 m or 60 m string of temperature and ocean pressure sensors, and a CT cell at 4 m depth. Some have an anemometer to measure surface wind speed and direction.

#### ***Deployments in 2014:***

Four ONR-funded, PG-manufactured UpTempO buoys were air-deployed by the Alaskan USCG in July and August 2014 in the Beaufort Sea at 72N and 73N along 140W on SIZRS flights. These were:

- One 2013 model held from the previous field season
- One 2014 model with spherical hull
- Two 2014 models with a new conical hull.

Many arctic buoys have transitioned to conical hulls (eg, the Ice-Tethered Profiler) in order to avoid a fairly common situation in which ice floes over-ride the hull, which prevents satellite data transmission. The conical shape enhances upward hull motion when ice floes converge. Two UpTempO buoys were deployed in July and two more in August. In the final deployment, a semi-hard landing onto the ocean occurred owing to late parachute deployment (it was partially deployed when the box hit the water). All buoys deployed successfully (including the final one) and sent data via Iridium satellite. We did have some sensor pod leakage issues, leading to significant drop-outs in our data stream. The cause was diagnosed as a bad seal between the Delrin plastic pod housing and the thermistor epoxy potting. Three of the buoys stopped reporting by October as the sea ice cover advanced; the fourth (a conical hull model) lasted until December, as it dragged along the 60 m isobath of the East Siberian Sea's continental slope.

In February 2015, we went to Kodiak to clarify parachute deployment procedures for our buoys via the C130. We used a specially made "dummy" box weighted normally but containing no buoy and tested various static line attachment points within the aircraft, "deploying" from a parked C130 onto a forklift. This test was very successful, codified by a simple instruction sheet made by K. Colburn that is handed to the loadmaster before each deployment. Part of this new procedure is a higher minimum altitude drop threshold of 500 feet, with a preferred altitude of 1000 feet, which greatly increases the odds of parachute deployment success.

#### ***Deployments in 2015:***

Four ONR-funded, PG-manufactured UpTempO buoys were air-deployed by the Alaskan USCG in July and August 2015 in the Beaufort Sea at 72N and 73N along 140W on SIZRS flights (**Figure 2**). These all had our new conical hulls. Other details:

- Two buoys had 25 m long sensor strings, and were deployed at 72N with the assumption of westward drift taking them over the shallow Chukchi Sea.
- Two buoys had 60 m long strings, and were deployed at 73N where westward drift would take them into deeper water.

A fifth Shell-funded, PG-manufactured 25 m long UpTempO buoy with anemometer was deployed in the northern Chukchi Sea on a SIZRS flight in September.

These buoys used a new epoxy and wiring system in the custom temperature pods which successfully prevented the leakage problems of 2014. All buoys deployed successfully, and are still reporting as of September, 2015. However, in high seas the new hulls proved to have stability issues, which caused stress on the connection to the sensor strings, causing loss of signal. This will motivate a hull redesign for next year. The first two buoys were deployed in ~50% ice concentration and very calm seas, resulting in a 5-6 day delay in deployment. The following week, we went to Kodiak to test the remaining buoys' transmission and parachute status. All was ok, but this required unpacking of the buoys, which is undesirable. For 2016 we will redesign the buoy box to allow for on-site testing in Alaska the day before deployment.

## **II. Buoy quality-control (QC) analysis:**

In summer 2015, we started a major QC analysis of all historical UpTempO data (including SIZRS), focusing on ocean temperature observations. This involves a number of steps: (i) standardized flagging for sensor failures across buoys and manufacturers, (ii) determining the buoy's position relative to the ice edge, (iii) determining the depth and ice/ocean status of each ocean temperature observation. The latter is particularly tricky for UpTempO buoys, which experience unusual conditions beyond simple "cable swing" that all ocean drifters with sensor strings see in response to wind forcing. IE we must also account for sensors that are pulled up into the ice pack via ridging/rafting, or are frozen into ice thermodynamically. We anticipate completion of this QC analysis by the end of calendar year 2015.

## **III. Ice edge loitering:**

Much of our scientific effort this year on this project was devoted to finishing and submitting our manuscript on ice edge "loitering," which (as always!) required more work than we suspected after our initial work which we presented in fall 2014 at the ONR review. We found a need to completely re-do our ice edge analysis to produce more stable, quantitative statistics on how frequent and prevalent loitering is within the Seasonal Ice Zone. This was very successful, and the paper was finally submitted to JGR in July (Steele and Ermold, 2015). We are very happy to report that it was recently accepted with minor revisions.

Also, our paper on enhanced synchrony in Beaufort Sea seasonal ice loss and prediction was published this year (Steele et al., 2015).

## RESULTS

### I. Initial analysis of buoy data:

Analysis of SIZRS UpTempO buoy data is ongoing. **Figure 3** shows data from a 2015 buoy that has drifted just north of the Beaufort Sea continental shelf break. It shows fascinating sub-surface intrusions of warm water, alternating with periods of more classic warm isothermal surface mixed layers over colder subsurface waters. In early September, the buoy crossed the mouth of Barrow Canyon, where both surface temperature and salinity rose dramatically. Thus this buoy tells us about both advective and vertical mixing processes in this area.

### II. Loitering during sea ice retreat:

We are interested in the relationship between ice retreat, wind forcing, and ocean warming. In the course of this investigation, we have discovered a previously unnoted behavior of sea ice retreat that occurs to varying extent every summer (Steele and Ermold, 2015). **Figure 4a** shows an example from summer 2012, where we have simply plotted the daily ice edge (0.15 concentration contour from passive microwave) for each day of summer as a thin black line. Thicker black lines indicate areas where the ice edge is not moving for several days, i.e., it is “loitering” in place. The phenomenon is also seen in the MASIE multi-sensor product from NSIDC. Loitering typically happens for ~4-11 days in any one location, but does not happen synchronously over the entire ice edge. Analysis of multiple summers indicates that some areas are more prone to loitering, e.g., the eastern Beaufort Sea, northern Chukchi Sea, and the Laptev Sea. When there is unusually rapid ice retreat as in summer 2012, an area of minimal loitering is created in the deep basins, as seen in the Canada Basin in Figure 4. The percent area of the SIZ that loiters each retreat season is declining from ~25% in the late 1980s to ~20% more recently (**Figure 4b**). This is because the SIZ area is increasing, while the absolute area where loitering happens is not changing.

The physical explanation for loitering is simple, and relies on the same physics that prevails at the winter maximum sea ice extent. As sea ice retreats in summer, it leaves open water behind which generally warms in response to air-sea heat flux and/or northward advection of warm water. If surface winds are southeasterly (in ice edge coordinates), they enhance this retreat. On the other hand, if they are northwesterly, ice floes are forced into warm open water, where they melt. If the wind is not too strong and the water is warm, these ice floes will melt, creating a stationary, i.e., “loitering,” ice edge. **Figure 5** illustrates this for an analysis of ice edge displacement over the retreat seasons of 2007-2013 in the Laptev Sea. The ice edge advances southward only when the wind is strong and the open water to the south is cold; in most cases with winds that encourage advance (i.e., northwesterly), very little ice edge motion is seen, i.e., loitering. Another way to view this dichotomy: For retreat-encouraging winds (i.e., southeasterly relative to the ice edge) of  $10 \text{ m s}^{-1}$ , the ice edge retreats  $\sim 20 \text{ km day}^{-1}$ , while for advance-encouraging winds (i.w., northwesterly relative to the ice edge) of the same magnitude ( $10 \text{ m s}^{-1}$ ), the ice edge advances less than  $5 \text{ km day}^{-1}$  when  $\text{SST} > 1^\circ\text{C}$  (but more when  $\text{SST} < 1^\circ\text{C}$ ).

Who cares about ice edge loitering? We speculate that this behavior strongly impacts the biophysical state of the air-ice-ocean system. Loitering should lead to enhanced melting, reduced floe size, surface layer nutrient depletion, and modified air-sea heat fluxes. Conversely, rapid retreat will likely be associated with minimal surface stratification. Clearly, more work is needed to explore these implications in detail.

## IMPACT/APPLICATIONS

UpTempO buoys are designed to better observed the warming of the upper ocean that occurs in response to sea ice retreat. Air-deployable SIZRS UpTempO buoys fill a crucial, unique niche in the over-all program, by providing placement opportunities when icebreakers don't operate and in locations where they may not travel owing to weather or ice conditions. Data from SIZRS buoys are available on the global GTS network for weather forecasting and other purposes. We plan to use SIZRS buoys in combination with other buoys to better understand the time/space scales of variability in upper ocean heat content, in part to create more objective deployment plans for the long-term. SIZRS buoys tell us how deep the atmospheric heating of seasonally exposed open water extends, which is crucial to understanding fall processes such as the pace of ice advance and impacts on the atmospheric boundary layer.

## RELATED PROJECTS

We are working with J. Zhang and A. Schweiger as part of ONR's Marginal Ice Zone DRI to improve sea ice – ocean modeling for the Arctic Ocean, with a focus on the MIZ of the Beaufort and Chukchi Seas. This grant provided major funding for our study of ice edge synchrony and prediction (Steele et al., 2015).

UpTempO buoys have been deployed in open water, in the MIZ, and in the main ice pack, and thus provide valuable validation data for the model. We are now working hard on a major new effort at validation of the model's ocean component, using UpTempO buoys and other in situ observations.

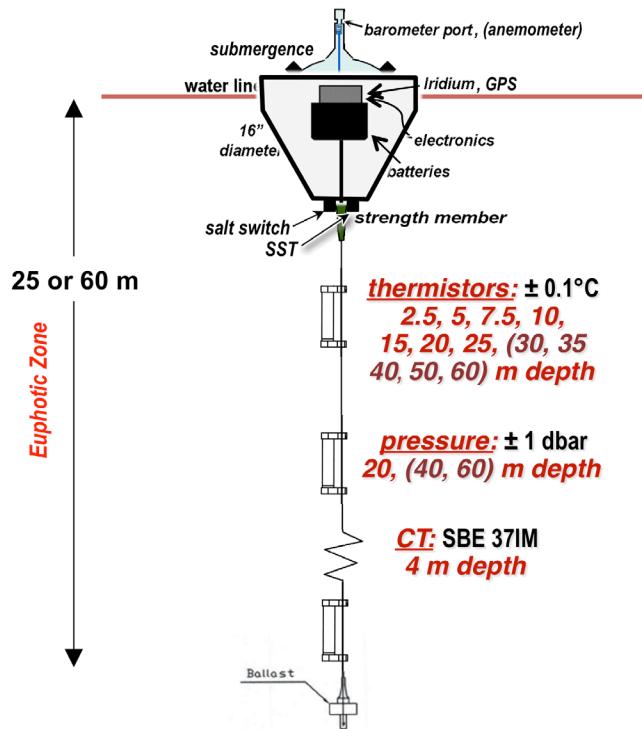
The SIZRS UpTempO buoy project is part of the over-all SIZRS project, where a group of scientists are working together to better understand the air-sea-ice coupling of the SIZ. The various components of the project are described in a separate progress report by J. Morison. UpTempO buoy data are used by graduate student S. Dewey to better understand variability between monthly SIZRS AxCTD drops, and by postdoc Z. Liu as a bottom boundary condition for his atmospheric modeling.

## PUBLICATIONS

Steele, M. and W. Ermold, Loitering of the retreating sea ice edge in the Arctic Seas, *J. Geophys. Res.*, accepted, 2015.

Steele, M., S. Dickinson, J. Zhang, and R. Lindsay, Seasonal ice loss in the Beaufort Sea: Toward synchrony and prediction, *J. Geophys. Res.*, 120, [10.1002/2014JC010247](https://doi.org/10.1002/2014JC010247), 2015.

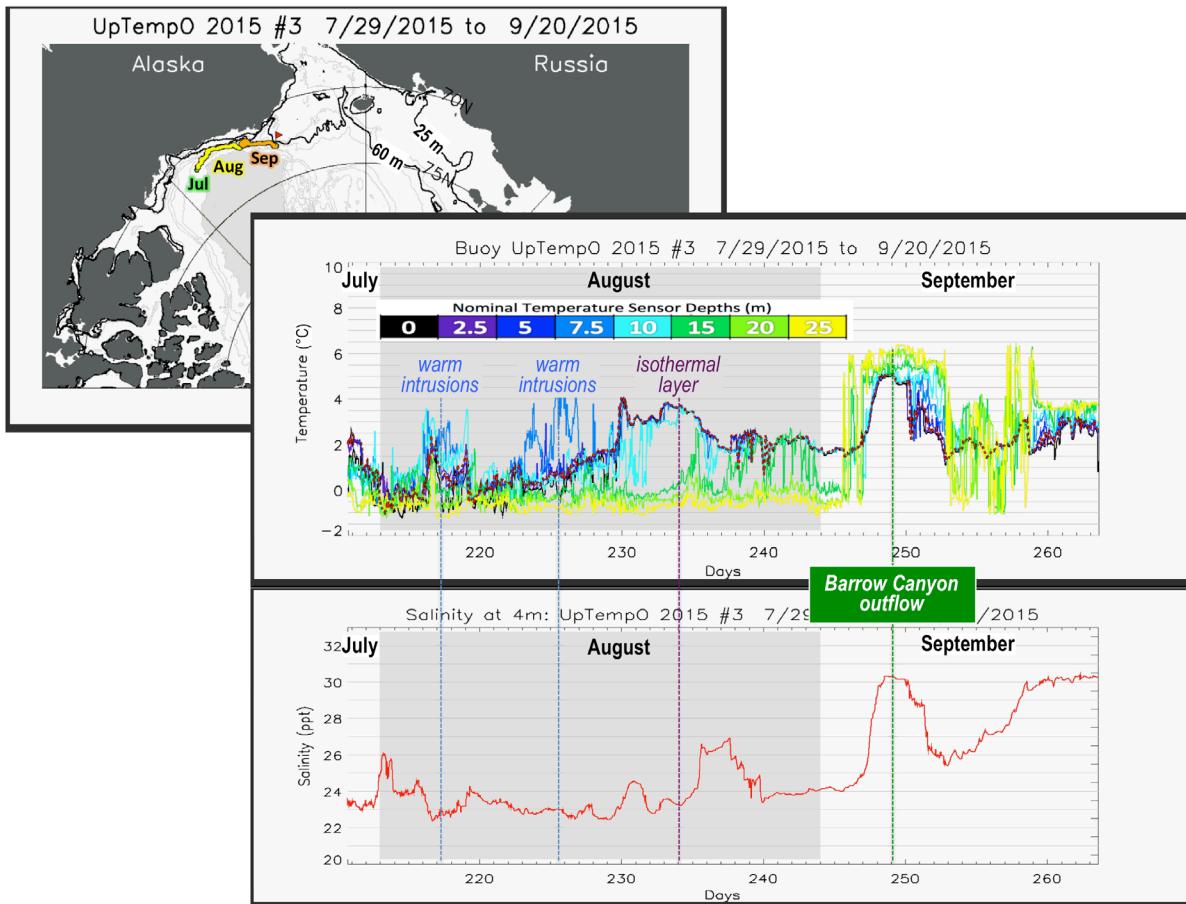
## 2015 SIZRS UpTempO buoy



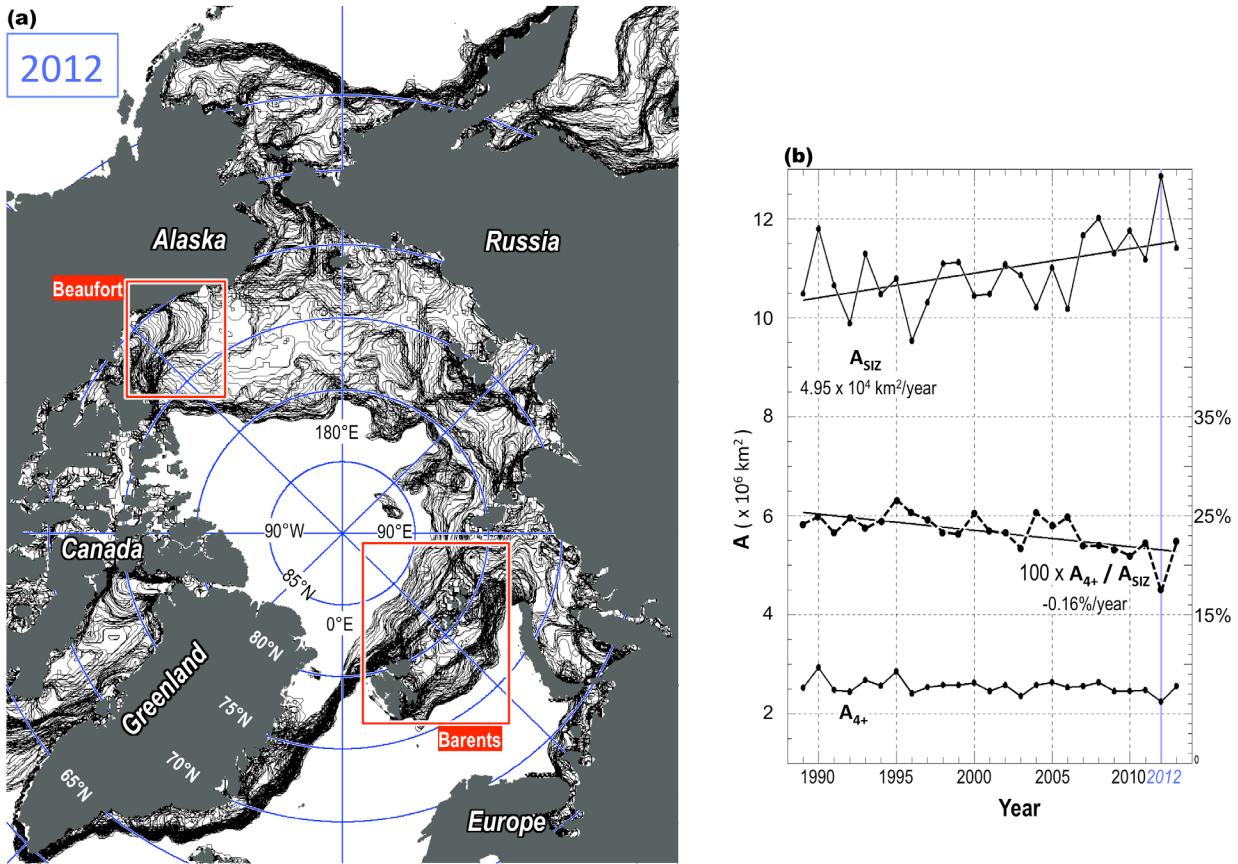
*Figure 1. SIZRS UpTempO buoy schematics. These buoys are made for us by Pacific Gyre (PG) Inc. in Oceanside, CA. In 2015, we deployed via SIZRS three 60 m long buoys and two 25 m long buoys; one of the short buoys had an anemometer.*



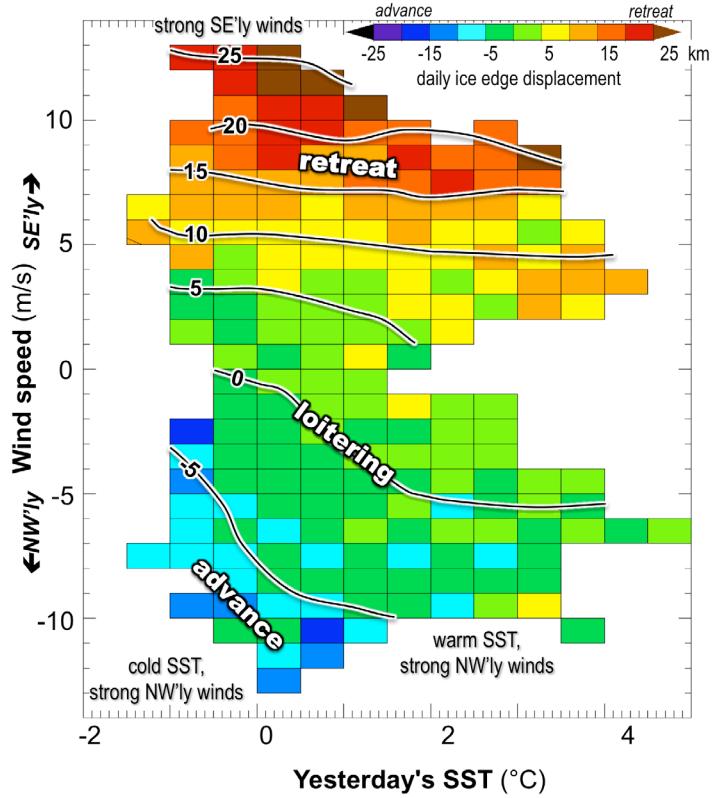
*Figure 2. Deployment via C130 aircraft of a SIZRS 2015 UpTempO buoy by the Alaskan United States Coast Guard (USCG). The buoy is packaged in a cardboard box that is strapped to a wooden pallet, attached by salt blocks that dissolve in hours-to-days, allowing the buoy to deploy. Image by K. Colburn, PSC/APL/UW.*



**Figure 3.** A 25 m SIZRS UpTempO buoy deployed in late July 2015 at ~ 72N, 140W. Shown (upper left) is the drift trajectory through late September, and time series of buoy thermistors (upper) and the 4 m depth salinity sensor time series (lower). Various stages in the drift are discussed in the text.



**Figure 4.** (a) The daily position of the 0.15 ice concentration contour from NSIDC NASA Team algorithm passive microwave data from SSMIS during the retreat season of 2012 (March–September). Each day's ice edge is a thin black line; thicker lines appear where the daily position "loiters" in place over more than one day. For example, red boxes illustrate loitering in the Beaufort and Barents Seas. Similar analysis for multiple summers indicates that certain areas are prone to "loitering" e.g., the eastern Beaufort, northern Chukchi, Laptev and other seas. Note an area of low loitering in the central Canada Basin, where the ice edge moved quickly northward during late July and August. Loitering periods are typically ~4–11 days, where we here define loitering as a minimum of 4 continuous days of the ice edge in a 25 km grid box. (b) The area of the Seasonal Ice Zone ( $A_{SIZ}$ ) is increasing in the last few decades, while the area of loitering  $A_{4+}$  is not. The result is a declining fraction  $A_{4+}/A_{SIZ}$  of the SIZ area that is covered by loitering.



**Figure 5.** Ice edge displacement (km, colored pixels and black contours) from the previous day to the present day, as a function of (i) open water SST within 100 km of the ice edge from the previous day, and (ii) surface wind speed in southeasterly (SE'ly) or northwesterly (NW'ly) directions (in ice edge coordinates) averaged over the previous and present days. Observations are every 25 km along all ice edges for every day of the retreat season in the Laptev Sea over the years 2007-2013. Pixels with fewer than 10 observations are not plotted.